

Cleaner production options for lead-acid battery manufacturing industry

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Abstract

Various demonstration projects conducted around the world have indicated that the cleaner production approach is more beneficial than the end-of-pipe type solutions. This study demonstrates how cleaner production can be applied to the lead-acid battery manufacturing industry, with focus on reduction/prevention of lead wastes. Various cleaner production options are discussed in relation to their technical and environmental feasibility. The effectiveness of good housekeeping practices, changing manufacturing processes, better process control and on-site recycling of waste generated are discussed. On-site recycling of scrap plates was found to provide 49% reduction in the quantity of lead waste generated demonstrating that cleaner production does not necessarily need extensive changes in present practices. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Lead-acid batteries are most commonly used for Starting, Ignition and Lighting (SLI) services in automobiles and trucks. Lead-acid batteries also provide motive power for everything from forklifts to submarines and are mainstays of the backup systems that provide power when the electrical grid fails. The development of the sealed-lead battery has allowed these batteries to be used in applications such as electronics that need a clean power source.

Two types of lead-acid battery are generally manufactured namely, wet-charged and dry charged. In a wet-charged lead-acid battery electrolytic solution (sulphuric acid) is filled in the battery, whereas, in a dry charged battery sulphuric acid is provided separately with the battery and is to be added only when the battery is being used. The manufacturing process of both these types of batteries is similar, except for the charging step. The

manufacturing process discussed herein is for a wet-charged lead-acid battery.

The aim of this paper is to discuss the environmental problems caused by the lead-acid battery manufacturing industry and to investigate some of the cleaner production options that can be applied to alleviate these problems. For the purpose of this study, a lead-acid battery manufacturing facility processing about 4000 tonnes of soft lead and 2500 tonnes of lead alloy over a duration of 10 months, was selected. Production data for a period of ten months was collected and this data has been considered as a basis for the study. Waste audit was performed to identify sources, quantities and types of lead wastes generated. The benefits of implementing the proposed cleaner production options and the barriers in their implementation are also discussed.

2. Waste generated from lead-acid battery manufacturing process

2.1. Overview of the manufacturing process

Similar to batteries of other types, lead-acid batteries are made-up of a positive electrode, a negative electrode

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and an electrolytic solution. All lead-acid batteries have the same general overall reaction for charge and discharge during their operation. On discharge, the lead dioxide (PbO_2) of the positive electrode and sponge lead (Pb) of the negative electrode are both converted to lead sulphate (PbSO_4). On charge, the lead sulphate in the positive electrode is converted to lead dioxide (PbO_2) and the lead sulphate in the negative electrode is converted to sponge lead. The electrolyte, sulphuric acid, is an active component in the reactions at both electrodes.

The manufacturing process of a lead-acid battery is that of applying a paste of lead oxide on a lead alloy grid and assembling the plates to form the battery. This basic process may be performed manually or by using highly automated machines. The type of process used depends upon the size of the company, its manufacturing capacity etc. Various methods are used all over the world to perform the above mentioned functions. A few of the major battery manufacturers make their own alloy, oxides, separators and containers/covers. Most battery manufacturers purchase rather than fabricate these materials. The flow diagram of a wet charged battery manufacturing process is shown in Fig. 1, which also indicates the areas where lead wastes are generated. The manufacturing process for lead-acid battery manufacturing process can be divided into the following sections:

2.1.1. Oxide milling

This is the process in which soft lead (99.97% pure) is converted into lead oxide. Solid bars of soft lead are melted at 400–425°C and the molten lead is oxidised to form lead oxide. The lead oxide, along with some percentage (about 26%) of free lead, is then passed into a cyclone separator and bag filter. The particles of lead oxide, are separated from the air stream in these equipments. The separated lead oxide is then transferred using screw conveyors into storage tanks, called silos. Air emissions from the bag filter contain lead particles, a source of pollution.

2.1.2. Grid casting

In here, bars of lead alloy are melted in a lead melting pot. The molten lead is then pumped into the grid moulds, which is then cooled by means of cooling water. The mould after cooling the alloy opens to discharge the grid. The moulded grid is then trimmed to remove the excess lead. The cuttings are then recycled into the lead pot. All these operations take place in one machine, which is completely automatic. During this process different types of lead alloys are used for casting of grids. Grids having different thickness are manufactured using these alloys. Grids are classified on the basis of the type of alloy used and the thickness of the grid casted. Melting of lead causes dross formation as well as generation of some solid wastes. Rejected grids are re-melted in the lead melting pot.

2.1.3. Paste manufacture

Two types of paste are manufactured, one for positive plates and the other for negative plates. The materials required for paste manufacture are lead oxide, sulphuric acid, water and other additives. These additives are different for positive and negative pastes. The above mentioned ingredients are mixed together in a fixed ratio (ratio of various ingredients depend upon the type of grid to be used for plate manufacture), in the paste mixer to form the paste which is then pasted on the grids. Lead oxide is the major ingredient used in paste manufacture with the paste containing about 85% of lead oxide. Evaporative losses occur during the paste formation. The vapours are treated in a scrubber and then discharged through a stack.

2.1.4. Grid pasting

Plates are formed as a result of applying paste onto grids. Grid pasting is done using machines. The pasting machine can be divided into four sections namely, feeding, pasting, drying and collection. The grids are fed onto the conveyor belt, by a feeding mechanism and paste applied on it and the pasted grid is passed between rollers where even spread of paste occurs. The paste is then dried in a flash drier and the dried plates are collected and stacked at the extreme end of the pasting machine. The plates are moved into the different sections namely, pasting, drying, and collection with the help of the belt conveyor system. The plates are classified depending upon the thickness of paste on a particular type of grid. Reject plates and excess paste applied onto the grids are generated in this section. Also, washing of equipment generates wastewater, which is contaminated with “paste”, which essentially contains lead. The washings are collected in the trade waste treatment facility on-site.

2.1.5. Plate curing

Curing is the process of exposing pasted positive and negative plates to a regime of controlled time (minimum 32 h), temperature (30–35°C) and relative humidity ($\geq 90\%$). This process converts the free lead in lead oxide, using oxygen from the surrounding air. The plates are allowed to cure for a minimum of 32 h. Care is also taken, to ensure that the maximum temperature of the plate does not exceed 60°C. The cured plates are then parted.

2.1.6. Plate parting

This operation is also performed using machines. The cured plates are fed into the parting machine by mechanical means. The plates are parted in the machine and then collected at the other end of the machine manually. The parted plates are collected and stacked for use in battery assembly. Rejects are generated in this section as well as some lead dust. Ventilation system in this area ensures

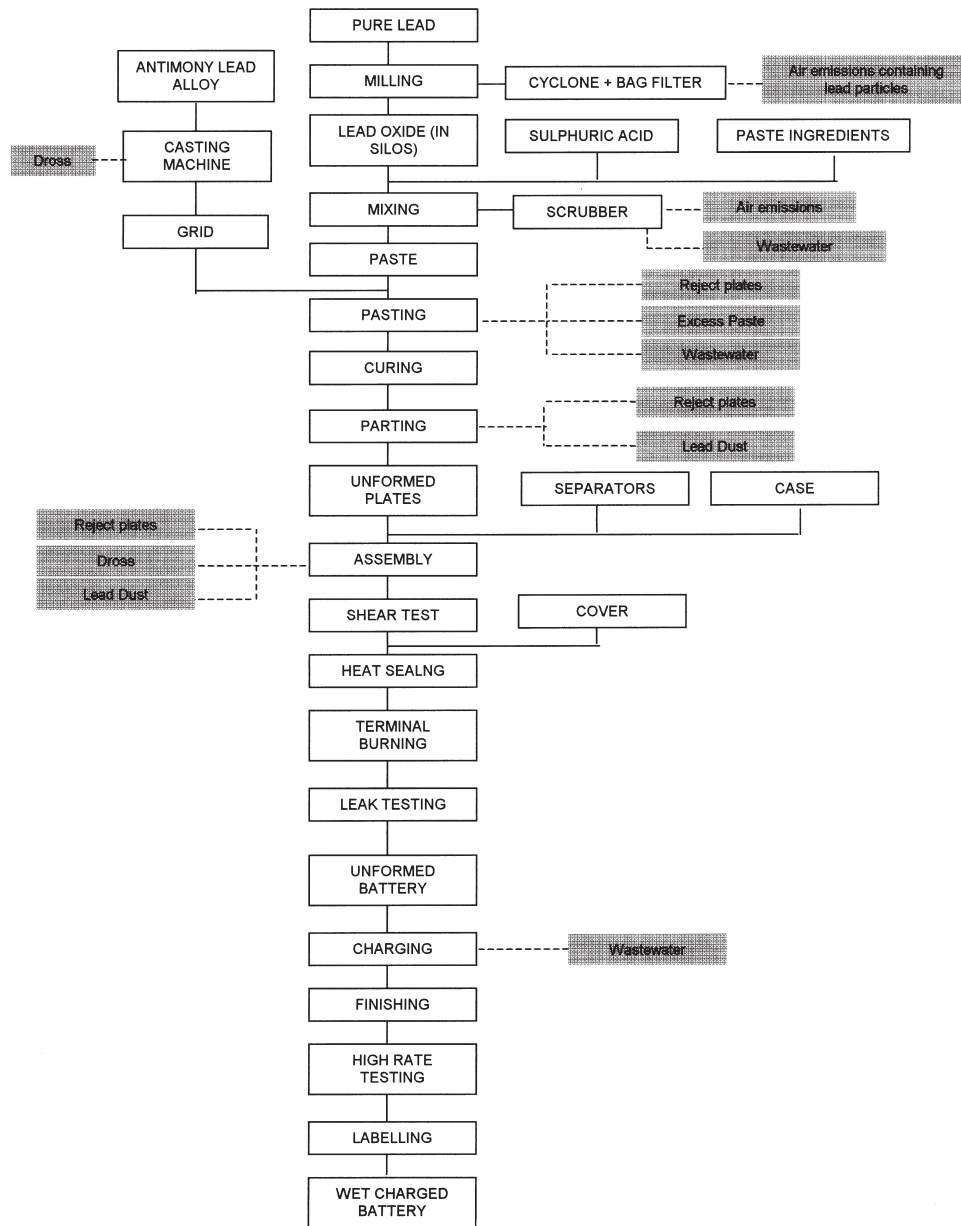


Fig. 1. Process flow diagram for wet charged lead-acid battery manufacturing process.

that lead dust generated is removed from the work area and discharged into the atmosphere through baghouse filter.

2.1.7. Battery assembly

The first operation in this area is that of enveloping of positive plates in a polythene sheet. This envelope acts as a separator that electrically isolates the positive and negative electrode. A mechanical vacuum system is used for feeding positive and negative plates for automatic stacking. The positive and negative plates are stacked together in the desired sequence and placed in a plastic case. The number of positive and negative plates in each battery depends upon the type of battery

being manufactured. Also, the type of positive or negative plates used depends upon the type of battery manufactured. The vacuum system generates lead dust due to feeding of plates, which is discharged to the atmosphere through baghouse filter.

The battery undergoes several other processes such as lug brushing, melting of lugs, cast on strap, intercell welding and fixing covers. All these operations are carried out before the plates are dropped in the plastic container. After the plates are assembled in the container they are mounted on a conveyor for the finishing operations which involves a shear test, heat sealing, terminal burning and leak testing. The product at this stage is called a dry uncharged battery. For a particular type of

battery having a specified capacity number and types of positive and negative plates are generally fixed. The activities in this section generate rejects of plates, dross and lead dust.

2.1.8. Charging

The dry uncharged battery now needs to be charged by addition of sulphuric acid. The battery is filled with sulphuric acid (specific gravity of 1245–1255 @ 25°C) and placed on tables and then cooled with water. The positive and negative terminals of the battery are connected to electric connections. The electric current is passed for a fixed duration of time during which the battery is charged. Different batteries have different currents for charging and different charging systems are used for it.

The operations of filling and emptying sulphuric acid from the battery are performed automatically using machines. Acid is filled by gravity flow into the cell to a level considerably above the plate tops. Charging is complete when there is no change in specific gravity over 3 h period. The sulphuric acid is then emptied from the batteries, a new solution of sulphuric acid is filled, and the battery is washed, labeled, tested and packed. The quantity of sulphuric acid filled in a battery varies with the type of battery manufactured. The wet charged battery is now ready for distribution and use. Wastewater is generated in this section as a result of charging and washing the batteries. This wastewater is acidic and contains sulphuric acid.

2.2. Waste/pollutants generated from process

Solid waste generated during the process consists of the following:

- Dross
- Scrap plates
- Scrap batteries
- Scrap plastic material
- Scrap envelope material
- Sludge.

Dross is an oxidised impurity which results during the melting of lead. Scrap batteries and scrap plates are generated as a result of manufacturing defects. Batteries which have been assembled and charged are checked and if found defective, are rejected, ending as scrap. Mal-functioning of machines in grid parting and battery assembly sections cause damage to plates. These are also scrapped. Improper pasting of plates results in its rejection as scrap. The settlement of suspended particles in the trade waste treatment facility generates sludge, which is removed from the treatment facility for off-site recycling. Table 1 indicates the quantity of lead waste generated from various operations over a 10 month period.

Reject battery containers and covers are the main

Table 1
Quantity of lead waste generated from various operations

	Source of waste generation	Quantity of wastegenerated (tonnes)
1	LOSS OF ALLOY AS:	
1.1	Scrapping of plates in pasting section	55.50
1.2	Scrapping of plates in grid parting and battery assembly section	106.40
1.3	Loss as dross (from grid casting and battery assembly sections)	63.10
1.4	TOTAL LOSS OF ALLOY	225.00
2	LOSS OF PASTE AS:	
2.1	Scrapping of plates in pasting section	100.38
2.2	Scrapping of plates in assembly section	192.20
2.3	Loss of paste as sludge (from pasting section, due to washing equipment and spillage)	156.65
2.4	TOTAL LOSS OF PASTE	449.28
	TOTAL QUANTITY OF LEAD WASTE GENERATED	674.28

source of scrap plastic generation. Besides, scrap plastic is also generated as a result of punching holes in the battery containers for intercell connections. These are disposed in a landfill.

Wastewater generated during the process is due to the following:

- Washing and cleaning of equipment
- Battery washing
- Discharge from scrubber
- Process cooling water being discharged.

Lead and sulphates are the major impurities in wastewater from this facility. The water used for cooling batteries in the wet room (charging section) and the water used to wash batteries consists of sulphate impurity. Wash down of floor and equipment in the pasting area generates wastewater that contains lead. This wastewater is treated in the trade waste treatment facility on site.

Air emissions during the process occur as a result of handling of plates, parting and collection of plates and other similar activities, which generate lead dust. The air in the plant is thus contaminated with lead particles. The ventilation system on site takes air from the site and discharges it into the atmosphere through a baghouse filter. Paste mixing operation has evaporative losses. The air, which contains lead particles, released from the paste mixer in the form of lead oxide is treated in a scrubber prior to discharge into the atmosphere.

Sulphur dioxide is emitted from the air emissions from the wet room and is discharged through a scrubber into

the atmosphere. Besides, flash drier, burners, vehicle movement on plant floor, all cause release of pollutants in air which are harmful to human and environmental health.

The lead-acid manufacturing industry also generates non-manufacturing wastes. They are generated from various activities such as handling, cleaning, packaging, depackaging etc. The waste generated as a result of these activities include:

- Wooden pallets
- Masonite and styrofoam sheets
- Paper and cardboard
- Scrap metals
- Plastic wrapping film
- Kitchen waste.

2.3. Health and environmental effects of battery manufacture

The main pollutant in a lead-acid battery manufacturing industry is lead. Lead is present in air, in the form of particulate, in solid form and in water, in suspended and dissolved form. Sulphate is present in air emissions and in wastewater.

Almost all food, water and air contain certain amount of lead. Thus, even if a person never worked with lead, he/she would still consume or inhale some of it during the course of his/her daily activities. Lead may enter the body through inhalation, ingestion or through the skin [1].

Each of us has a normal bodyload of lead. If absorption is unchecked, the body will accumulate it faster than it can be eliminated. Continued absorption of lead could result in constipation, anaemia, abnormal sperm, lack of appetite, weight loss, nausea, abdominal pain, muscle aches, joint tenderness. Lead also effects nerve conduction and at high lead levels kidneys may be affected.

Children are more susceptible to lead poisoning. Lead is especially toxic to children and the young of other species. Chronic exposure to lead has significant effect on intelligence and neuropsychological performance of children [2].

A problem inherent in the study of lead poisoning is that the symptoms are largely non-specific. This can lead to difficulties in the diagnosis of cases of over exposure to lead. The best documented effects of lead on blood are its interference with the biosynthesis of heam, which is essentially the production of haemoglobin. The most profound effects of lead poisoning are undoubtedly those associated with severe damage to the central nervous system. At high levels of exposure to lead, brain damage may resulting stupor, convulsions and/or coma and may progress to death [1].

Air borne lead is removed from atmosphere by wet

and dry deposition causing contamination of environmental media. Lead may interact detrimentally with aquatic life. Precise behaviour of lead in aquatic media and effects on aquatic life will be determined by the chemistry of lead. Once contaminated, soil is liable to remain polluted with lead, this will effect soil fertility [1].

Plants may incorporate lead. Accumulation of lead in grasses is a potential hazard to livestock. Large changes in the lead content of soil are required to produce changes in the aerial parts of the plants as compared to changes in aerial lead concentration are closely reflected in the leaf lead concentration. Lead contamination of food arising from treatment of land with industrially contaminated sewage sludge or lead containing chemical fertilisers and pesticides has been examined [3].

The following sections of the paper mainly concentrates on preventing the lead waste from the battery manufacturing process by investigating some of the cleaner production options.

3. Cleaner production options for lead-acid battery manufacture

Prevention of waste as a result of manufacturing activities of batteries is the major focus of this section. Thus product reformulation and raw material substitution options have not been dealt with in detail. Good housekeeping practices, changing manufacturing processes, better process control, on-site recycling are other methods which can prevent or reduce the amount of lead waste generated. Using these techniques of cleaner production (CP) and waste reduction various options are discussed.

3.1. CP options for scrap plates

Scrap plates are generated in the grid pasting, grid parting and battery assembly sections. In the grid pasting section improper feeding of grids occurs causing the grids to be scrapped. Furthermore, after the pasting and drying of the plates they are rejected for improper pasting. All these activities lead to the generation of scrap plates. Also, the moisture content of the paste on the plates is determined frequently. The plates used for testing are also scrapped. In the plate parting section improper feeding of the plates into the parting machine leads to rejection of plates that are eventually scrapped. Feeding of the parted plates in the enveloping machine is the cause of scrap generation in the battery assembly area. Again, improper feeding of the plates is the cause of scrap generation. Table 2 illustrates the quantity of scrap plates generated in pasting, grid parting and battery assembly areas.

Table 2
Quantity of scrap plates generated^a

Operation	Loss of grids/plates	Loss of paste (tonnes)	Oxide used in paste manufacture (tonnes)	Soft lead used in oxide manufacture (tonnes)
	In terms of alloy (tonnes)			
Grid pasting	55.51	100.00	86.64	81.96
Grid parting and battery assembly	106.35	100.38	86.96	82.26
Total	161.86			

^a Note: average weight of grid=0.0498 kg; 0.8664 kg of oxide required for manufacture of 1 kg paste; 0.9640 kg of soft lead required to manufacture 1 kg of oxide.

The following CP options are suggested for the prevention/reduction of scrap plates:

- 1a. Cast grid as a single unit;
- 1b. Re-feed the plates;
- 1c. Washing and recycling of plates in grid pasting section;
- 1d. Recycling of plates from plate parting and battery assembly section;

3.1.1. Option 1a: cast grids as single unit

Grids, which are casted in pairs, are separated into two after the curing operations to facilitate assembly into the battery. The grids can be casted as one unit with one lug, as shown in Fig. 2.

Benefits: The parting of the grids generates lead scrap. If the grids are manufactured as a single unit with lug at one end only it will eliminate the plate parting section and wastes generated in this section.

Barriers: The feeding mechanism in pasting machine and various equipment used for handling of grids from grid casting stage to grid patting stage are of such design

and mechanism that lugs at two end would be required to handle the grids. Grids with one lug would make the above operations difficult to conduct. Thus, if grids are manufactured singularly they will need to have two lugs. One lug will have to be cut for the plate to be used in the battery. Hence, a singular unit will also require parting operation. Moreover, if grids are to be cast as single units with one lug, the existing equipment (moulds, feeding and handling mechanism/equipment of grids) would become redundant and new equipment would have to be installed, which could be cost prohibitive.

3.1.2. Option 1b: Re-feed the plates

The plates rejected in the grid pasting section can be recycled into the feeding end of the pasting machine.

Benefits: This would bring about a reduction in the quantity of scrap plates generated due to improper pasting.

Barriers: This option is not technically possible as the plates once fed cannot be re-fed as the feeding mechanism will get affected and obstruct more plates in the rotation mechanism. This will generate more waste and hence, this option would not be feasible.

3.1.3. Option 1c: Washing and recycling of plates in grid pasting section

The plates, which are rejected after the drying operation due to improper application of paste, can be collected in a tank or container. The plates can then be washed using a water jet and the grids separated from the water. The grids can be dried and the water can be allowed to settle. The paste will settle and can be reused in the pasting operation in a fixed ratio with the virgin paste. The clear water from the top of the tank or container can be used as process water to be mixed with paste or for cleaning purposes. The dried grids can be melted in lead melting pots in the grid casting section.

Benefits: Assuming all plates are recycled, implementation of this option will lead to saving 55.51 tonnes of lead alloy and 81.96 tonnes of soft lead (in terms of paste saved from being scrapped). Thus, 137.46 tonnes of scarp shall be reduced due to this practice (refer to Table 2).

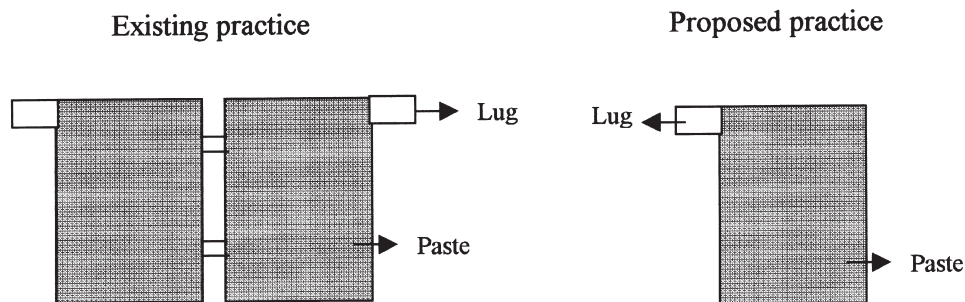


Fig. 2. Casting grids as a single unit.

As this option has no environmental impacts and no major capital investment, the returns are beneficial both financially and environmentally.

Barriers: The feasibility of recycling of paste removed from the plates needs to be investigated as it may not be possible to recycle all the paste into the paste mixer. The moisture content of the paste will be a critical parameter to be monitored prior to recycling. Also the grids need to be dried with care to ensure that water does not enter the lead melting pots when the grids are recycled into them.

3.1.4. Option 1d: Recycling of plates from plate parting and battery assembly section

The scrapped plates from the grid parting and battery manufacturing section cannot be recycled in the same manner as mentioned above (option 1c). The plates can be washed, the grids dried and recycled. The wash water can be allowed to settle suspended particles and the clear water can be recycled.

Barriers: The sediment of the paste cannot be recycled, as this cannot be used as paste. This is because of the curing operation where the reaction has already taken place and hence the paste cannot be recycled. It has to be disposed as sludge.

The removal of paste from the plates after it has been cured is difficult as compared to removal of paste after the pasting operation. Thus, the washing of plates will involve washing using a jet spray. Physical breaking of the paste will also be required before water is sprayed for removal of paste.

Benefits: This does bring about saving of grids, but creates another waste stream of sludge. It still is worth considering and if found feasible should be implemented. It will reduce, 106.35 tonnes of lead alloy in the form of grids is being recycled (refer to Table 2).

3.2. CP options for lead in sludge from the trade waste treatment facility

The paste, which is spilled on the floor of the grid pasting area, is washed into the drain, which is then transferred to the trade waste treatment facility. This waste stream is settled in a pit in the trade waste treatment facility. Sludge is also formed in the wastewater treatment facility due to chemical precipitation reaction. The total quantity of sludge generated from the wastewater treatment facility is about 385 tonnes. The settled sludge is removed and stored in 205 litre drums on site. The sludge is once again allowed to settle in these drums, water decanted and drum filled with sludge is then shipped to the smelter. The sludge from the various pits is pumped together, and hence, the sludge is a mixture of paste and sulphate precipitates.

To prevent/reduce the generation and transportation of sludge, the following options are suggested:

- 2a. Dewatering of sludge
- 2b. Segregation of paste from precipitates
- 2c. Segregation at source.

3.2.1. Option 2a: Dewatering of sludge

The sludge can be dewatered using a belt press or a plate and frame filter press. Both these equipments are technically suitable for this purpose. Centrifuges can also be used for the purpose of sludge dewatering.

Benefits: This option does not prevent the lead waste from being generated, but reduces the volume of lead waste, which needs to be sent to the smelter for off site recycling. The water from the filter press can be treated and recycled on site. Dewatering reduces the volume of sludge being transported to the smelter.

The reduction in the volume of sludge would depend upon the equipment selected for dewatering. Thus, the saving in transportation costs would depend upon the volume reduction achieved. This saving would be offset by the equipment purchase and maintenance costs.

Barriers: This option requires an initial investment in equipment.

3.2.2. Option 2b: Segregation of paste from precipitates

The paste sludge can be segregated from the sulphate precipitates (formed due to chemical precipitation reaction in the wastewater treatment facility) by using different pumps for pumping paste sludge and sulphate precipitates. The paste sludge can then be dewatered (using a filter press or belt press) and the dewatered paste can be used in the grid pasting section.

Benefits: This option would facilitate reduction in the quantity of sludge sent for off-site disposal. Also, the quantity of paste to be manufactured will be reduced due to recycling activity.

Barriers: Since this paste is a mixture of positive and negative pastes it can be mixed in the negative paste mixer only. Also there exists a limit to the amount of recycled paste that can be added into the negative paste mixer in this manner, i.e. a ratio of recycled paste to the new paste.

3.2.3. Option 2c: Segregation at source

The positive and negative pastes are pasted on different machines. Thus, the paste which is spilled on the floor can be collected separately on the shop floor in the existing pits (separate pits of positive and negative paste) and pumped into the dewatering equipment (one type of paste for each cycle) and the cake can then be recycled into the paste mixer.

Benefits: Paste (collected and dewatered) can be reused in both the positive paste mixer (recycled positive spilled paste) and negative paste mixer (recycled negative spilled paste). This will reduce the quantity of paste

required to be manufactured. Also, since the waste paste is not settled in the trade waste treatment facility, operating costs of the trade waste facility would be reduced. Implementation of this option would reduce the quantity of sludge to be sent for off-site recycling.

Barriers: The moisture content of the paste is important and a certain percentage has to be maintained for reuse in paste mix. Thus, the filter press selected (for dewatering of sludge) should be able to maintain this percentage.

Recycling of both positive and negative pastes can be achieved by this method. This will reduce greater amount of sludge than option 2b. However, it will be difficult to segregate the positive and negative paste spills on the plant floor. Thus, a mixture of positive and negative pastes will be obtained. This will result in recycling the paste in the negative paste mixer only making this option similar to option 2b (mentioned above). This option also requires investment in a dewatering equipment.

3.3. CP options for the dross

Dross is formed by the oxidation of the lead alloy in the lead melting pots of the grid casting section. This dross floats on the surface of molten lead in the lead melting pots and is physically removed from the pots. The dross is then stored in drums and sent for disposal to the smelter. The quantity of dross formed in the grid casting section is 46.4 tonnes. Further, the melting of lead takes place in the battery assembly section. The melting of lead causes dross formation in battery assembly section. The quantity of dross formed in battery assembly section is 16.7 tonnes.

Nitrogen blanketing of the lead melting pots in the grid casting section can reduce the dross formation in the pots.

Benefits: Reduction in the quantity of dross generation leading to reduction in consumption of lead alloy for casting of grids.

Barriers: This option requires extensive capital investment, which would not justify the cost savings obtained from dross reduction.

3.4. CP options for loss of oxide in paste

Improper feeding of grids into the pasting machines and cleaning of hoppers (for feeding of paste from paste mixers) for maintenance cause paste to be wasted. A distance is maintained between two successive grids (i.e. time lag exists in feeding mechanism of grids into the pasting machine) which is fed into the pasting hopper. A small amount of paste is deposited in this gap (i.e. distance between successive grids on the conveyor belt of the pasting machine). This paste is dropped off the conveyor belt and is collected and recycled back into the

hopper. Cleaning and maintenance of equipment (pasting machine) also causes generation of sludge. When the plates are being transferred using conveyors paste tends to stick on the rollers (used to evenly spread paste on grids) which is then washed during maintenance and the paste transferred to the wash water from the rollers generating sludge. All the waste paste generated is transferred to the wastewater treatment facility and amounts to 156.56 tonnes.

The various prevention/reduction options in this case are as follows:

- 4a. Hopper operation
- 4b. Material of construction
- 4c. Improved process control.

3.4.1. Option 4a: Hopper operation

This is basically to do with improved operating procedures and better control and maintenance over the hopper operation (i.e. feeding of paste on conveyor belts, to be applied onto grids).

Benefits: This option will reduce the amount of paste being wasted and would bring about reduction in the operation costs of trade waste treatment facility as the quantity of waste water to be treated would reduce.

3.4.2. Option 4b: Material of construction

The hoppers and rollers can have a non-stick coating on them. This will prevent the sticking of paste on this equipment. A collection tank can be placed below the rollers to collect excess paste, which falls off during the operations. This can then be recycled.

Benefits: During maintenance and washing operation of the equipment, the quantity of paste ending as sludge will be reduced as no sludge would be stuck to the equipment. This will also reduce water consumption as less cleaning will be required. The quantity of paste ending up in the trade waste treatment facility will also be reduced leading to reduced operating costs.

3.4.3. Option 4c: Improved process control

Instrumentation/automation of the process of applying paste on the grids can reduce the waste being generated during this process. If the pasting operation is automated, then thickness of paste can be controlled. This will prevent the generation of excess paste as sludge. Also, with automation of the grid pasting process, the number of plates being scrapped can also be reduced.

Benefits: This option would not only reduce the quantity of plates scrapped but also would reduce the amount of paste sludge generated. Thus, leading to reduced operation costs of the trade waste treatment facility and reduction in the purchase of soft lead (for oxide formation) and lead alloy (for grid casting).

Barriers: This option is a prevention option and is a

long term option. It may require a large capital investment and several changes in the existing equipment. This will however prevent the generation of lead sludge at the source. A new process technology may be required to do this. Although this is a prevention option, the reduction option of washing the plates and recycling the plates and grids (option 1d) could turn out to be more feasible, economically.

3.5. CP options for lead dust in air

The collection of pasted plates in the pasting section, collection of parted plates in the grid parting section and the collection of enveloped plates in the battery assembly are the major sources of lead dust. Besides, paste mixing causes evaporative losses, which contains lead oxide. In the oxide milling section, the conversion of lead into lead oxide and the subsequent separation also causes generation of lead particles. The vacuum suction feeding system in the battery assembly section also causes generation of air pollution.

As it is the handling of the plates which is of major concern to generation of lead pollution, much cannot be done to prevent or reduce it. Thus, treatment of the pollutant is the best solution in this case. Using face masks for operators and ventilation systems could be the best practical option to deal with this issue. The collected filter dust has no use on site and thus, cannot be recycled on-site. It is best disposed to the smelter.

3.5.1. Option 5a: Replace vacuum system (mechanical system)

Replacing the vacuum system used for feeding of plates in the battery assembly section will reduce the amount of air pollution in terms of lead particulate. Also, the volume of air to be treated in the baghouse filters of the mechanical system will be reduced.

Benefits: Improved workplace environment due to reduction in generation of lead dust.

Barriers: Using a non-vacuum system for feeding of plates in the battery assembly section would need replacement of existing equipment. Also, three baghouse filters are installed at the facility for treatment of lead dust discharged from the ventilation system. Even if the existing vacuum system of battery assembly area is replaced, the need of baghouse filters (3 nos.) is not likely to be reduced (volumetric flow rate of vacuum feeding system is very low compared to volumetric flow rate of ventilation system).

3.6. CP options for lead particles in stormwater

The lead particles which are emitted from the stacks, after the baghouse filters, tend to settle on site (the baghouse filters are used as pollution control equipment for lead dusts generated in the facility). These settled par-

ticles are then washed away during the event of a storm and thus cause lead pollution of stormwater. The sample analysis of the selected storm water drains, also indicate the presence of lead in the stormwater. Prevention/reduction options in this case would be that of prevention/reduction of lead particles from entering the storm water drain and collection and treatment of stormwater. The following options are suggested:

- 6a. Improve efficiency of equipment
- 6b. Filtration and recycling of storm water.

3.6.1. Option 6a: Improve efficiency of pollution control equipment

Improving the efficiency of the pollution control equipment (baghouse filters) will reduce the amount of lead emitted from the stacks.

Benefits: As a result of improved efficiency of pollution control equipment, the lead particles settled on site will reduce, which will correspondingly reduce lead concentration in stormwater.

Barriers: The baghouse filters are operating at removal efficiencies (of particulate matter) of greater than 95%. Improving the efficiency of the pollution control equipment further would involve very high costs and could require replacement of the existing equipment.

3.6.2. Option 6b: Filtration and recycling of stormwater

The stormwater can be collected into a tank and then passed through a filter to remove fine particles from the collected stormwater and recycle the filtered water on site. A cartridge filter could be used for this purpose. Also, a Valveless Autowash Gravity (VAG) filter could be used for this purpose. The VAG filter involves no instrumentation and maintenance. It backwashes automatically and is thus more suitable for this application as compared to the cartridge filter (however, cost of VAG filter is substantially higher than cartridge filters).

Benefits: Using a filtration system will improve the quality of water. Thus, water could be mixed with paste and used as process water reducing the water usage. Reduction in stormwater pollution would also be achieved as stormwater is collected and reused on-site.

Barriers: This option creates waste streams (that of particles collected at the filter media and backwash water used for cleaning of filters media), which will have to be managed suitably.

The quantity of water used at the facility is about 150–180 m³/day. Hence, collection and filtration of stormwater could prove to be expensive as compared to the cost of water purchased from the authorities. Detailed design of the stormwater collection and filtration system would enable quantification cost of stormwater.

4. Conclusions

The benefits and barriers to implementation of various options for reduction/prevention of lead wastes have been discussed in the previous section. Recycling of scrap plates from grid pasting and grid parting and battery assembly areas (Options 1c and 1d), would bring about a reduction of 383.86 tonnes of waste generated (alloy and paste). This brings about a reduction of 48.99% of the total quantity of lead waste generated.

This study also demonstrates that to improve the environmental performance it is not always necessary to make changes to the existing processes or equipment. Simple practices such as onsite recycling of waste generated can enhance the environmental performance with minimum capital investment.

Prior to implementation of a cleaner production option, the environmental aspects of the proposed should be considered. It is very likely that while one pollutant/waste stream is addressed, another stream could emerge, as discussed in option for stormwater recycling and recycling of scrap plates. Thus, the overall environmental impact of implementation of the option should be considered. Also, the payback on implementation option should be determined, where possible.

The reduction of the quantity of waste generated during the lead-acid battery manufacturing process has several advantages. Besides saving money for the industry, it reduces consumption of materials. With the reduction in utilisation of lead, mining of lead ore could be reduced

minimising the environmental problems associated with such activities.

As less lead waste is to be transported, it reduces hazards associated with the transportation of waste and also the consumption of fuel for transportation. Problems associated with on site storage are also reduced. This will cause a reduction of licence requirements for storage of regulated wastes.

Implementation of cleaner production options will also improve the image of the industry. The legal liability will also be reduced as a result of reduction in the amount of waste generated. In case of transportation, if spills occur, the impact would be reduced and the spill can be cleared relatively quickly, with reduced amount of waste being transported.

Recycling of trade wastewater and improving collection efficiency of battery wash water in wet room are some housekeeping methods that can reduce the quantity of wastewater generated. Turning off flash dryers when no plates are to be dried, stopping the movement of conveyor belts when no material is to be transferred, extinguishing welding flames, when not in use are simple housekeeping methods, that will reduce energy consumption.

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